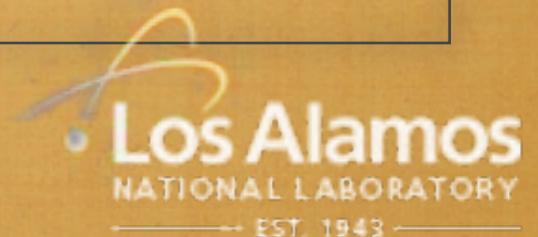


# **DECAY ANGULAR DISTRIBUTION OF J/ $\psi$ MEASURED BY PHENIX**

**KWANGBOK LEE  
CESAR LUIZ DA SILVA  
FOR THE PHENIX COLLABORATION  
LOS ALAMOS NATIONAL LAB**

**DIS 2011 - NEWPORT NEWS, VIRGINIA APR 11-16**



# Decay Angular Distribution

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- decay angular distribution of spin  $m=1/2$  particle from a spin  $J_z=\pm 1$  particle derived from:
  - density matrix elements of production amplitude
  - parity conservation rules

$$\rho_{mm'} = \begin{pmatrix} \rho_{11} & \rho_{10} & \rho_{1-1} \\ \rho_{01} & \rho_{00} & \rho_{0-1} \\ \rho_{-11} & \rho_{-10} & \rho_{-1-1} \end{pmatrix}$$

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spin longitudinal	$W_L = \rho_{00}$
spin transverse	$W_T = \rho_{11} + \rho_{-1-1}$
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$$\lambda_\vartheta = \frac{W_T - W_L}{W_T + W_L}$$

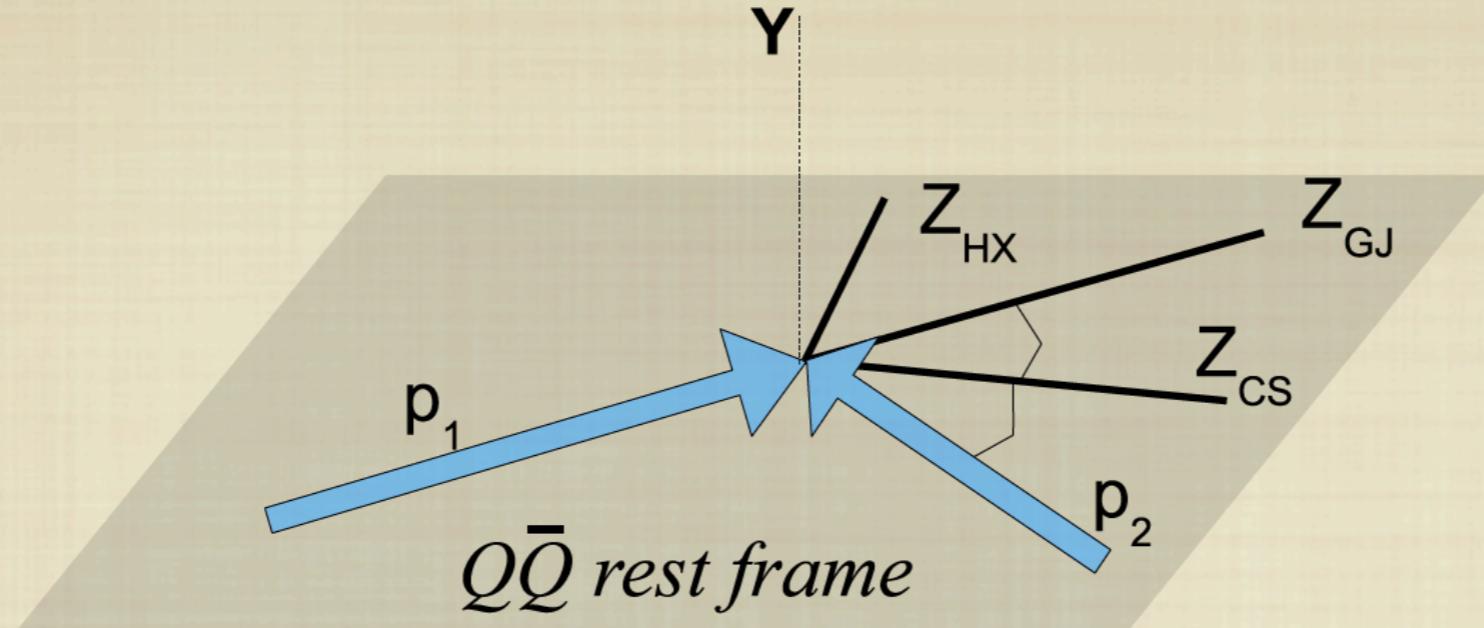
$$\lambda_\phi = 2W_{\Delta\Delta} / (W_T + W_L)$$

$$\lambda_{\vartheta\phi} = \sqrt{2}W_\Delta / (W_T + W_L)$$

$$\frac{dN}{d\cos\vartheta d\varphi} \propto 1 + \lambda_\vartheta \cos^2\vartheta + \lambda_{\vartheta\phi} \sin 2\vartheta \cos\varphi + \lambda_\phi \sin^2\vartheta \cos 2\varphi$$

We measure lepton decay angular distribution of  $J/\psi$

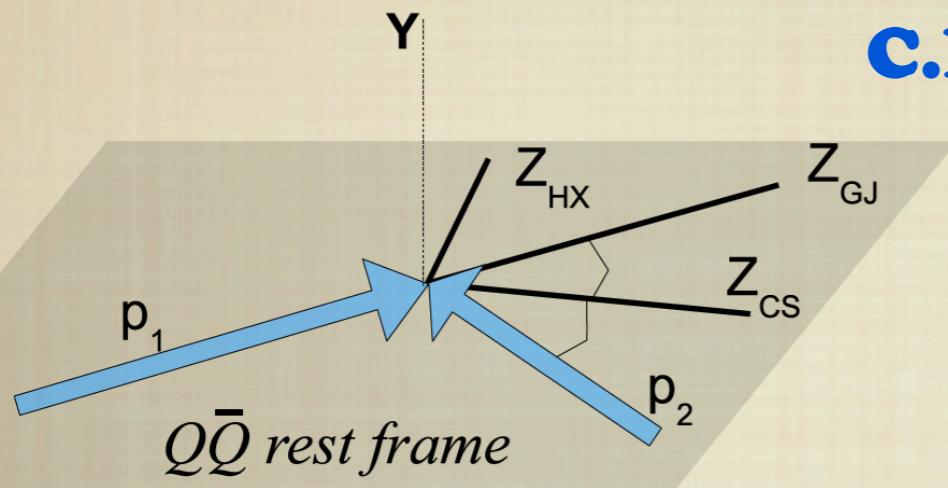
# Frames



- angles  $\vartheta, \varphi$  of the positive lepton are measured relative to a longitudinal direction  $\hat{z}$
- the longitudinal direction  $\hat{z}$  can be defined as
  - **Helicity (HX):**  $J/\psi$  momentum direction in the  $J/\psi$  rest frame
  - **Collins-Soper (CS):** bisector btw. direction of the first colliding parton and the opposite of the second colliding parton in the  $J/\psi$  rest frame
  - **Gottfried-Jackson (GJ):** one of the colliding hadrons momentum in the  $J/\psi$  rest frame

# Frame conversions

□ parameters obtained in one frame can be converted in other frames [P.Faccioli, C.Lourenco, J.Seixas - PRD81,111502(2010)]



$\delta \equiv$  rotation around  $y$  axis

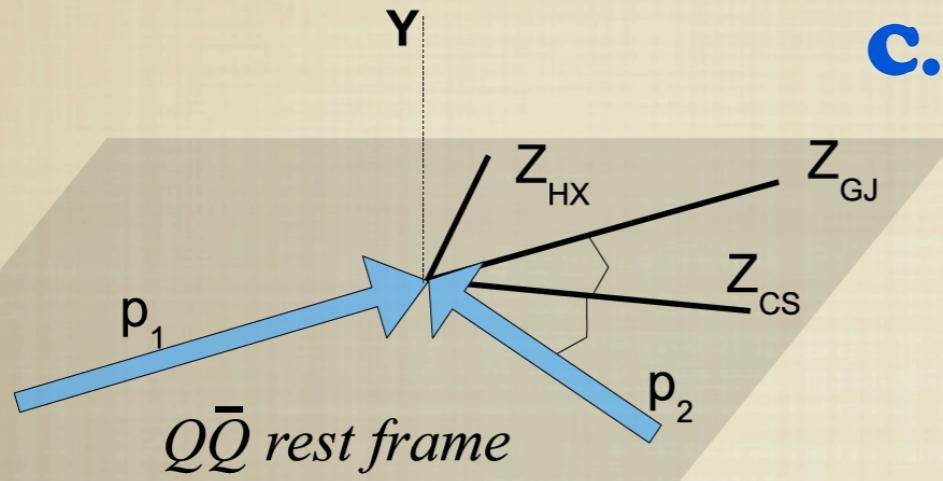
$$\lambda_{\vartheta}^{(B)} = \frac{\lambda_{\vartheta}^{(A)} - 3\Lambda}{1 + \Lambda}, \quad \lambda_{\varphi}^{(B)} = \frac{\lambda_{\varphi}^{(A)} + \Lambda}{1 + \Lambda},$$

$$\lambda_{\vartheta\varphi}^{(B)} = \frac{\lambda_{\vartheta\varphi}^{(A)} \cos 2\delta - \frac{1}{2}(\lambda_{\vartheta}^{(A)} - \lambda_{\varphi}^{(A)}) \sin 2\delta}{1 + \Lambda},$$

$$\Lambda = \frac{1}{2}(\lambda_{\vartheta}^{(A)} - \lambda_{\varphi}^{(A)}) \sin^2 \delta - \frac{1}{2} \lambda_{\vartheta\varphi}^{(A)} \sin 2\delta.$$

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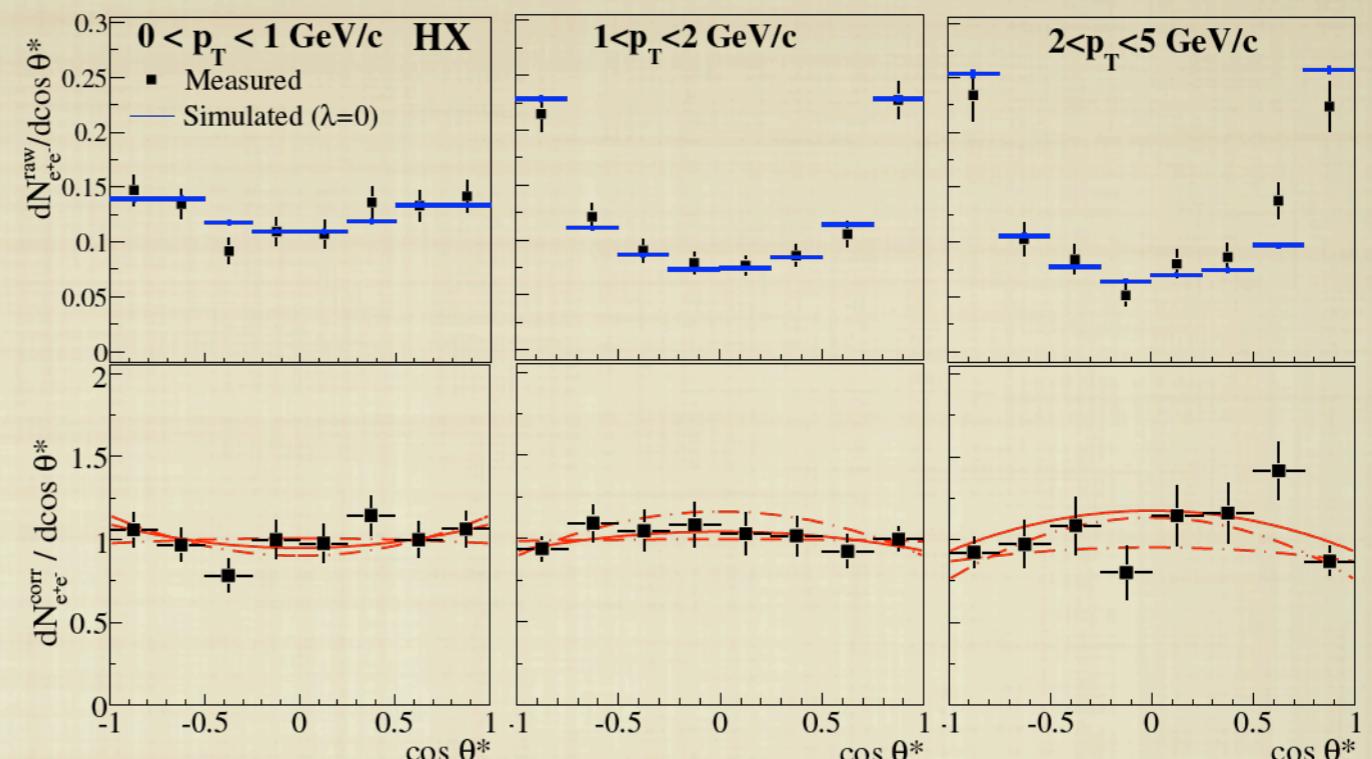
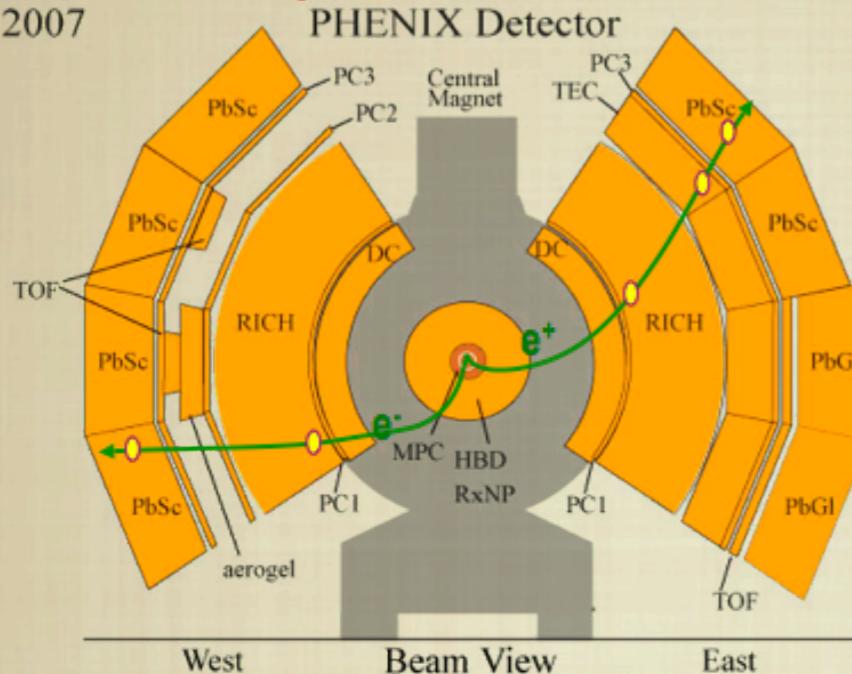
- possible to derive a frame invariant spin alignment parameter

$$\tilde{\lambda} = \frac{\lambda_{\vartheta} + 3\lambda_{\varphi}}{1 - \lambda_{\varphi}}$$

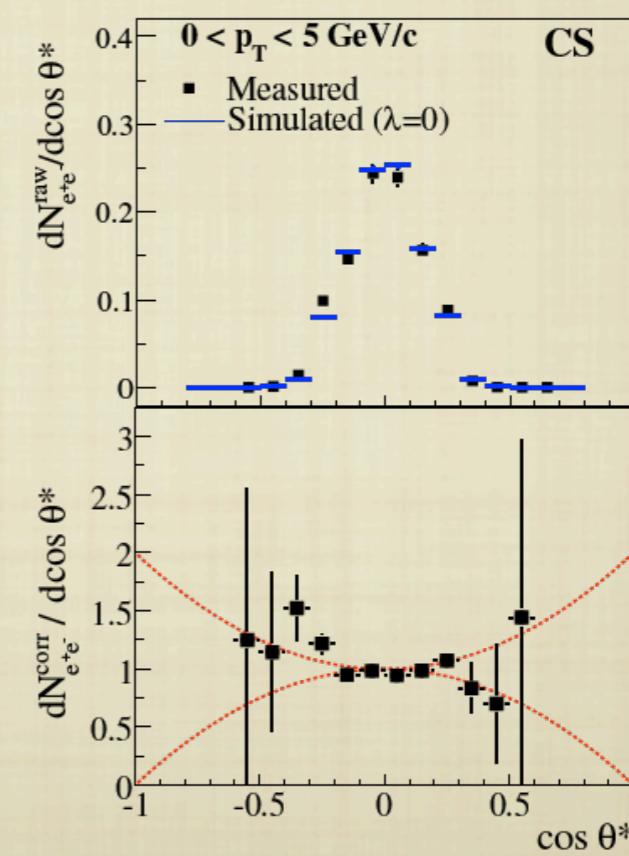
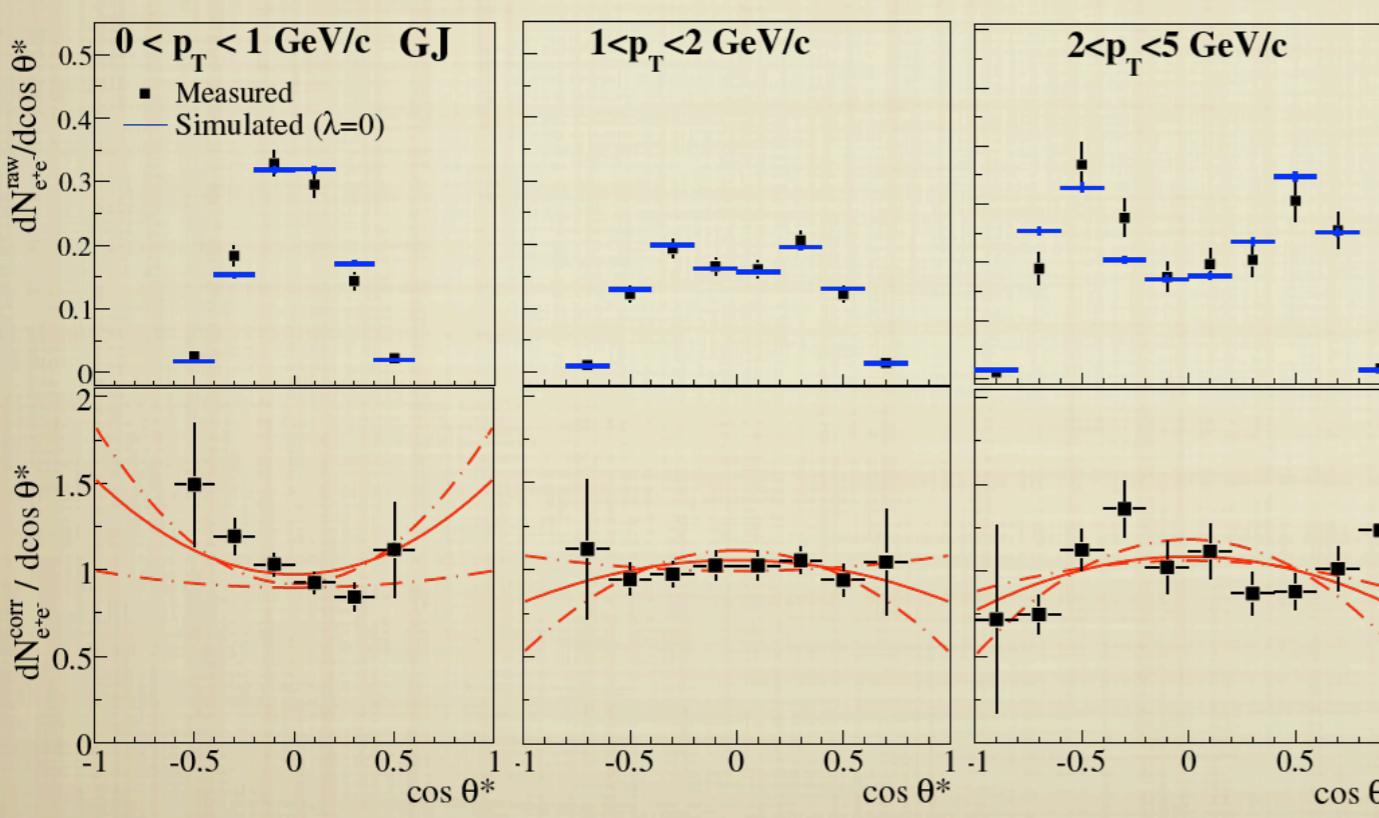
# PHENIX Acceptance

**mid-rapidity |  $\eta$  | < 0.35**

2007

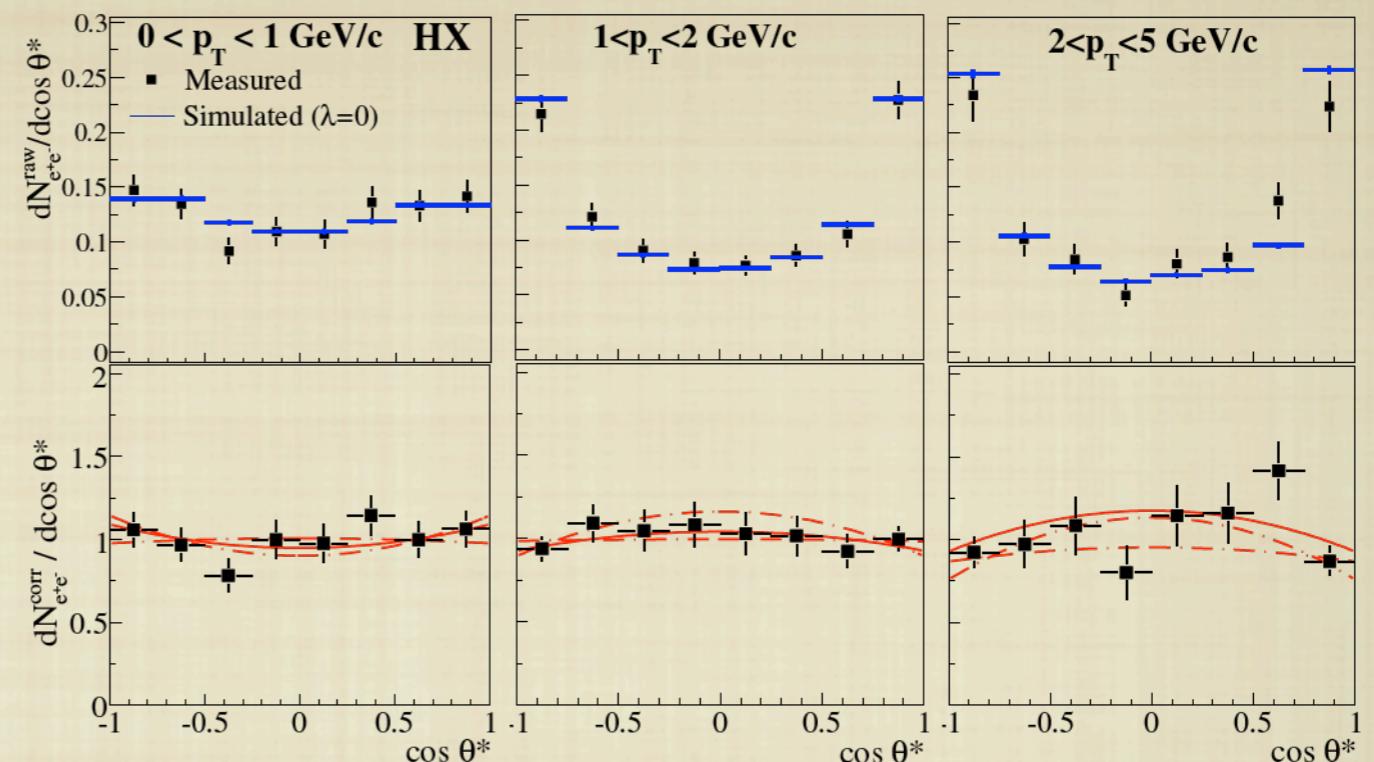
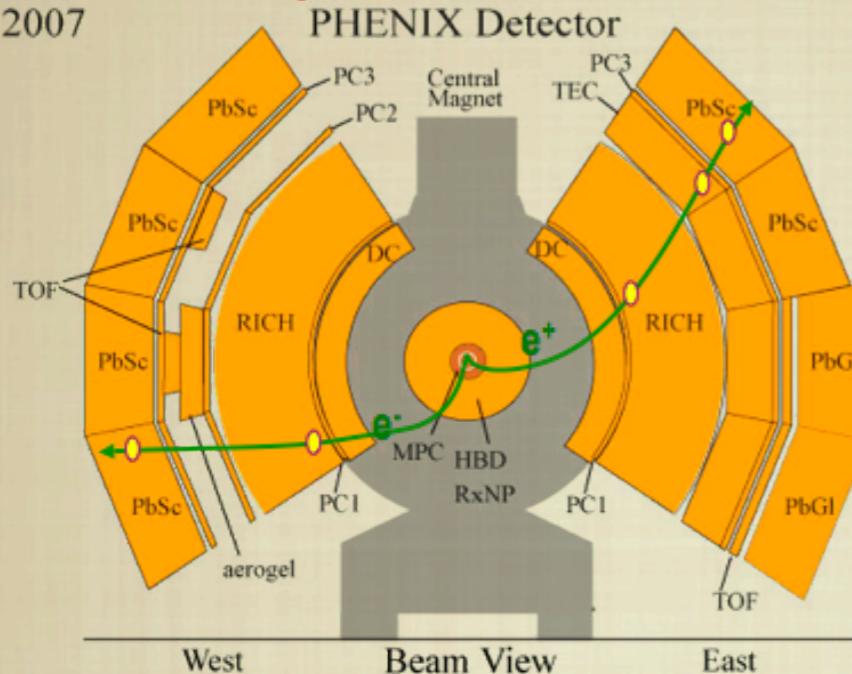


**only cos  $\varphi$  for now**

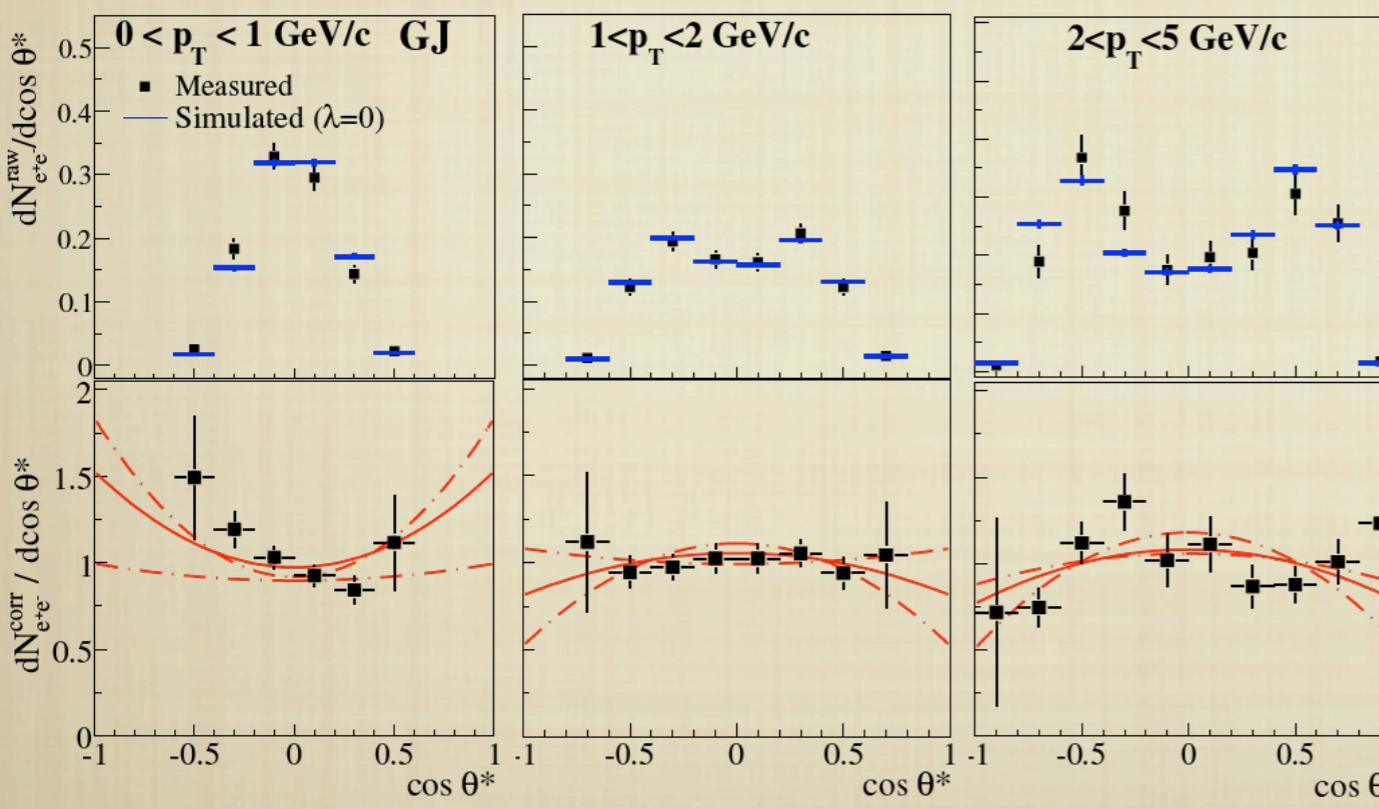


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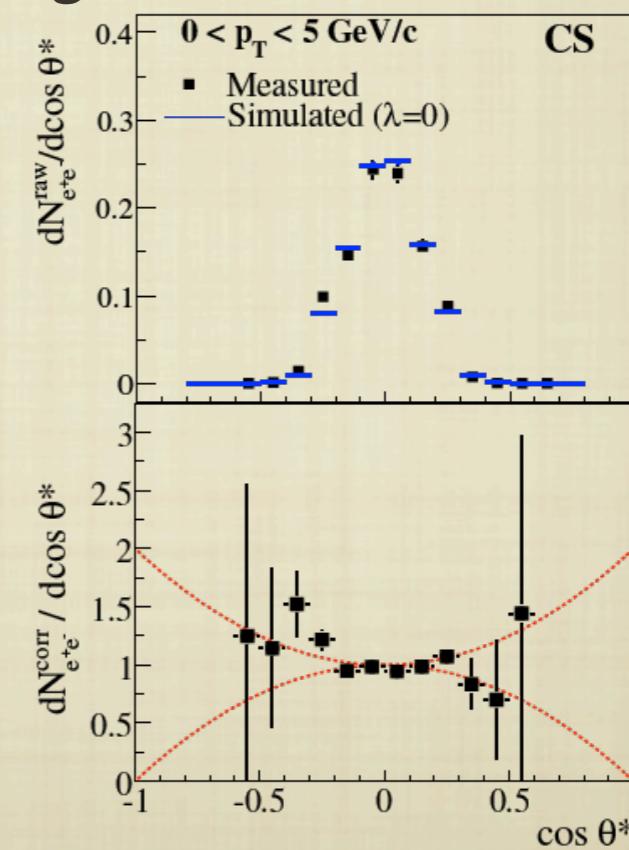
2007



**only  $\cos \vartheta$  for now**



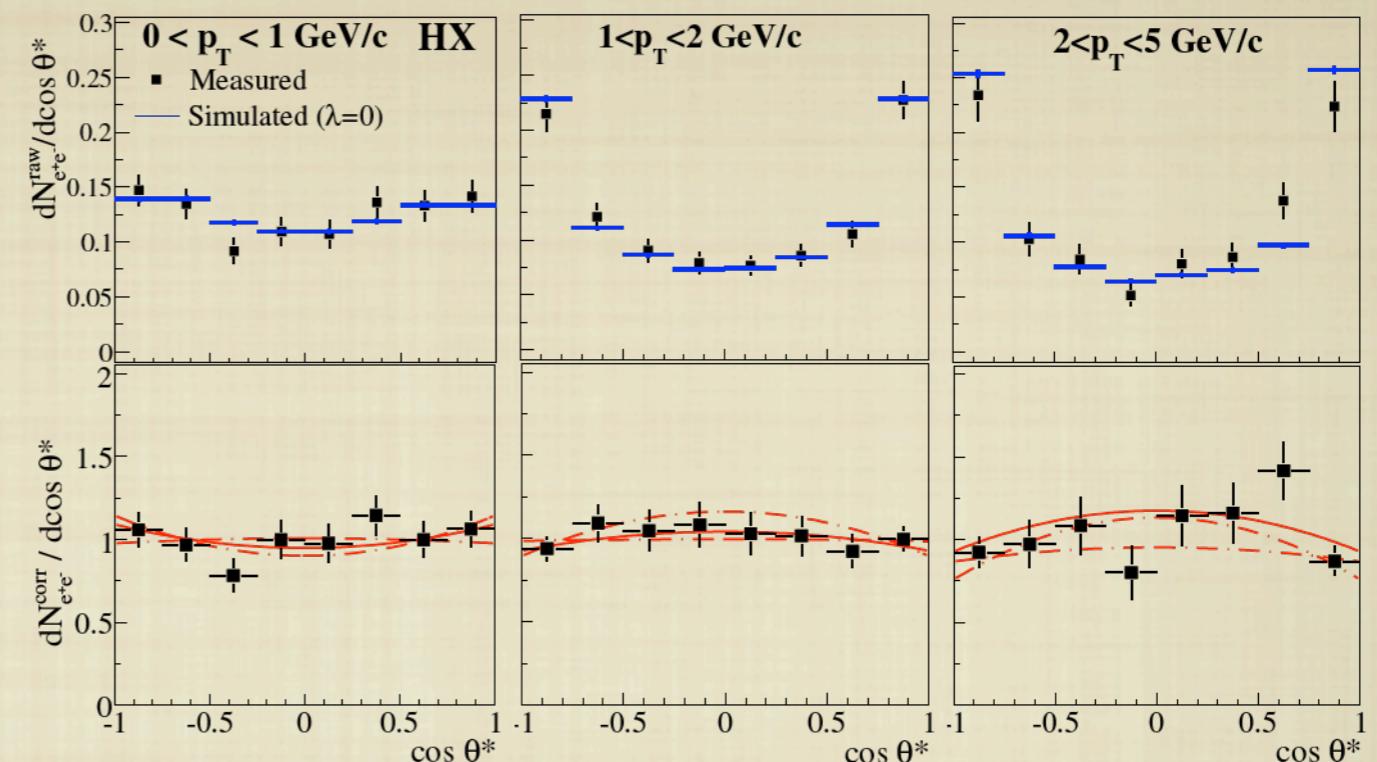
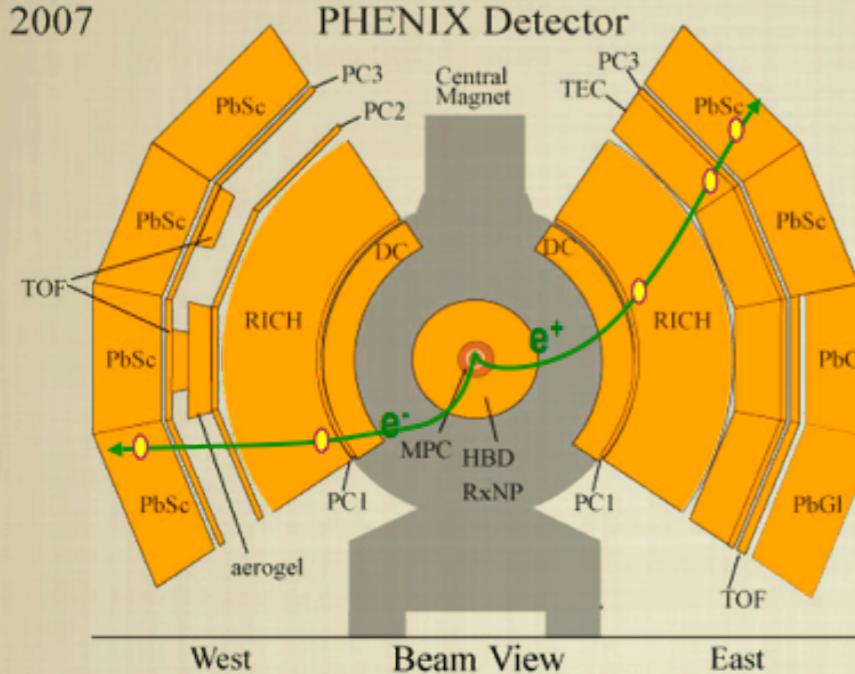
**good coverage of the  $\vartheta$  angular distribution in HX frame**



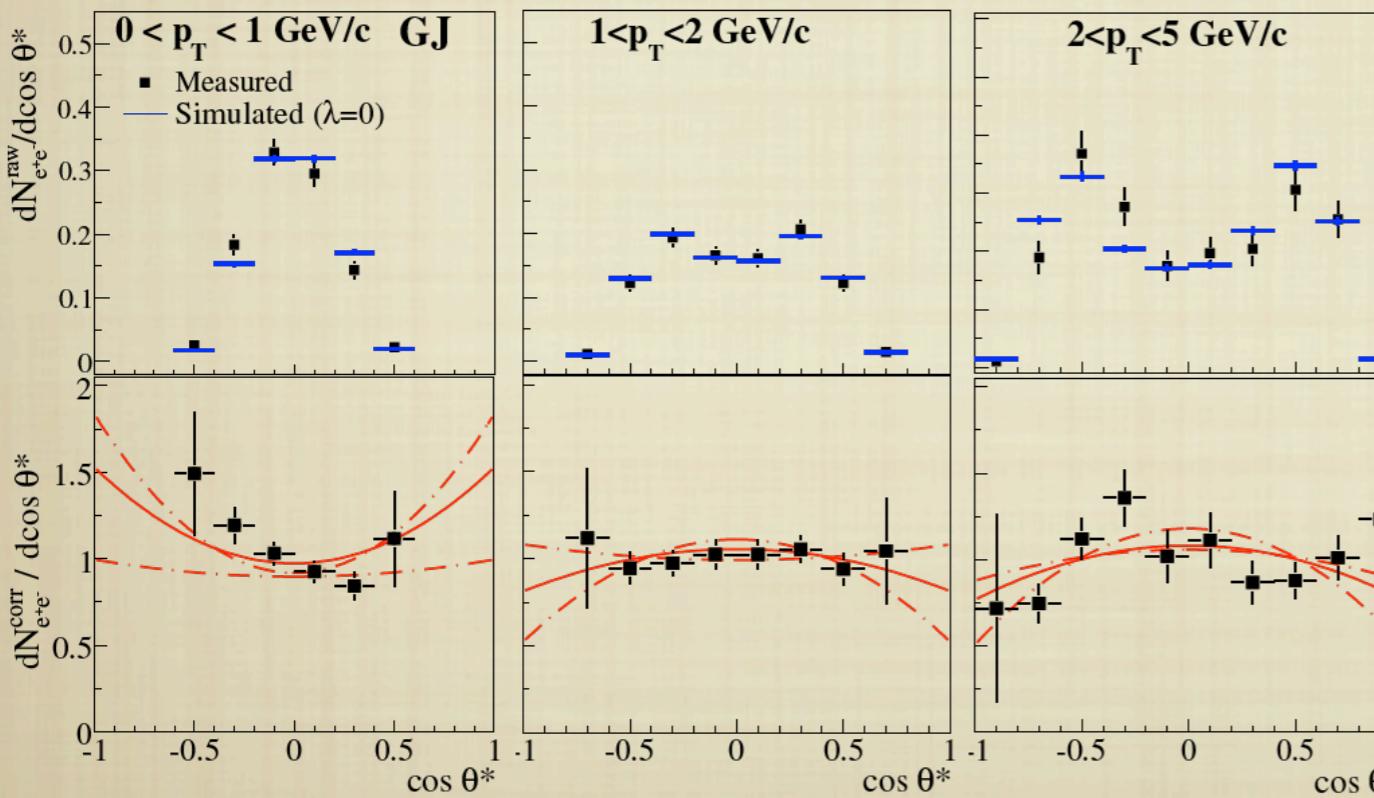
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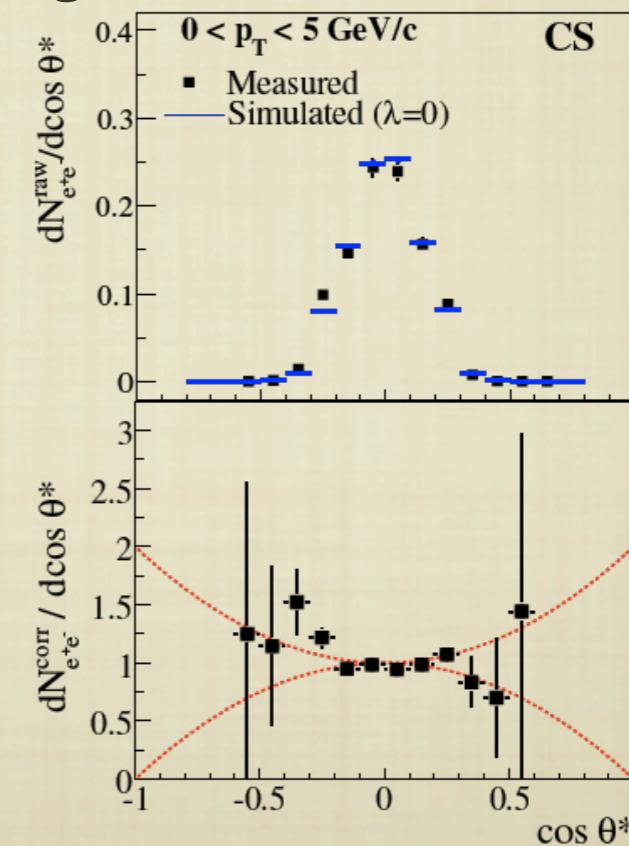
2007



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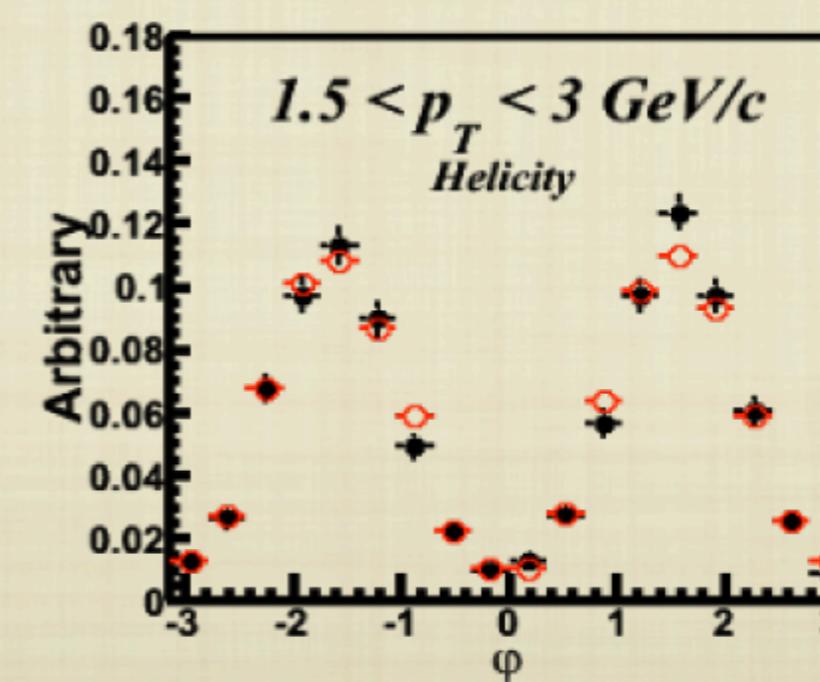
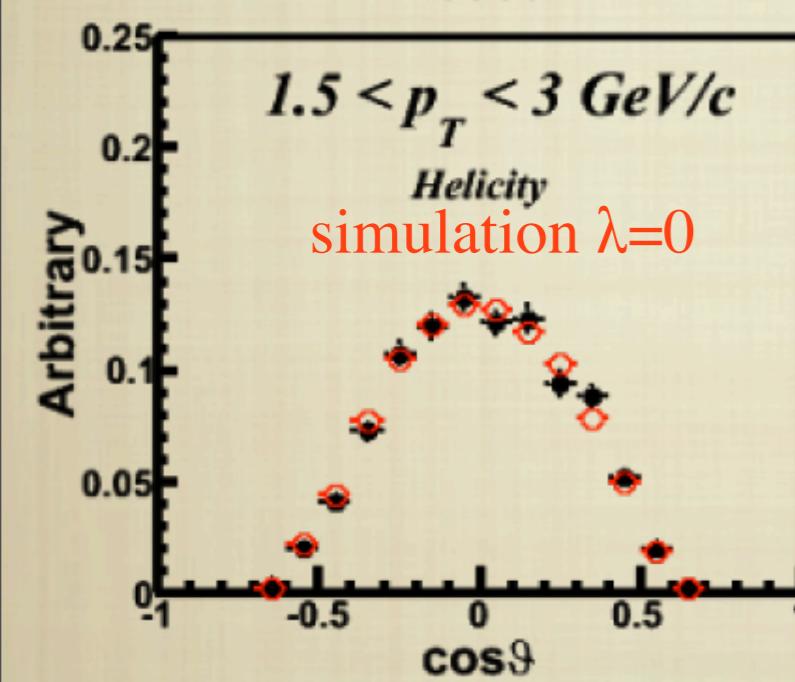
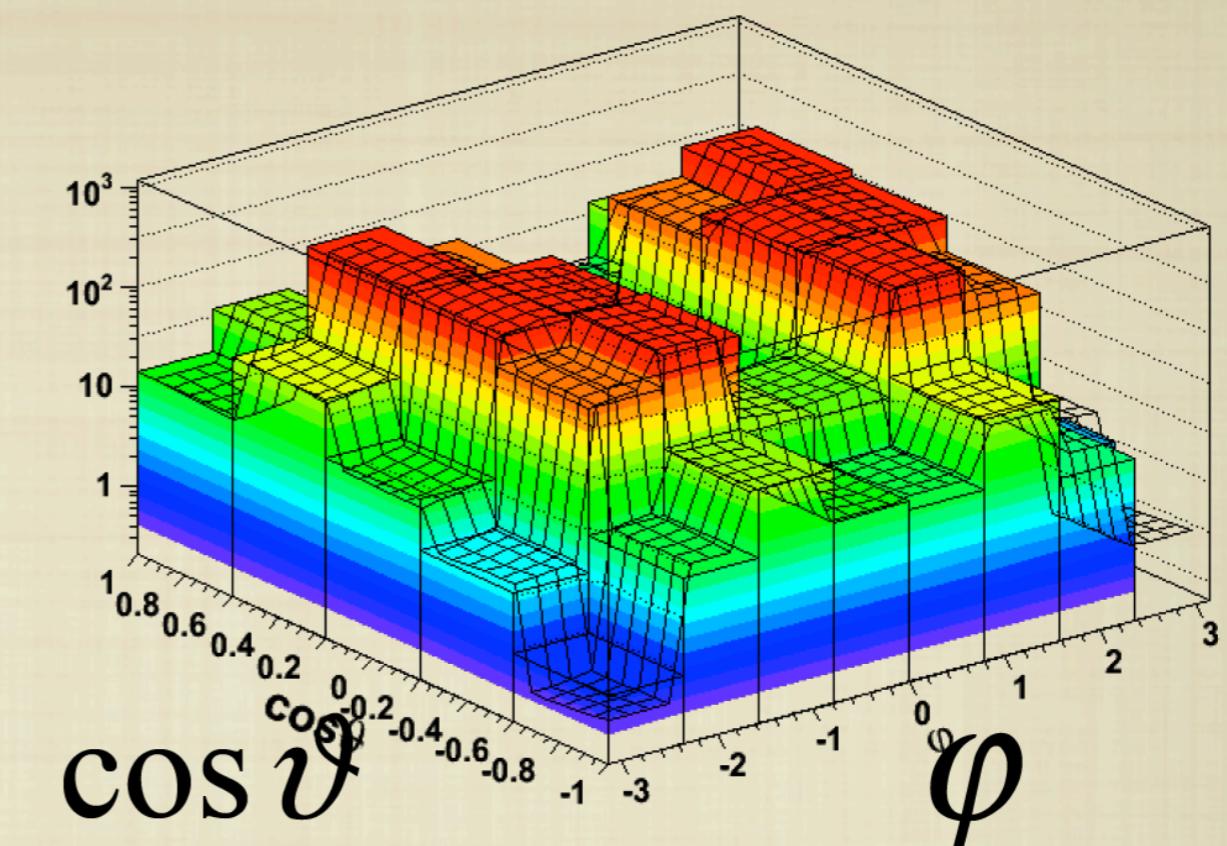
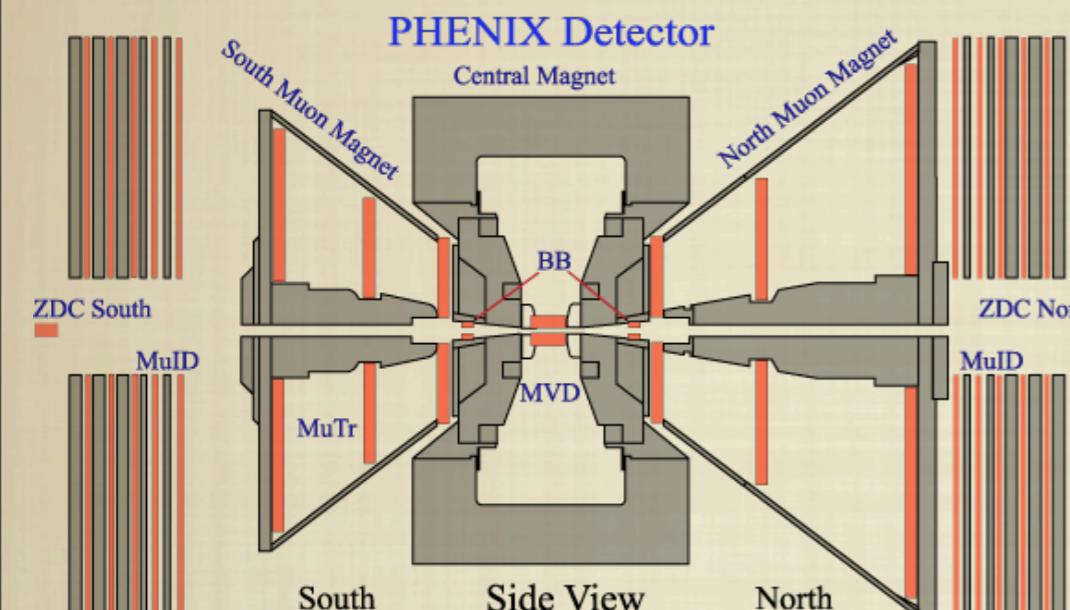
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**measurement requires excellent knowledge of the detector acceptance**

# PHENIX Acceptance

**forward and backward  
rapidity  $1.2 < |y| < 2.2$**



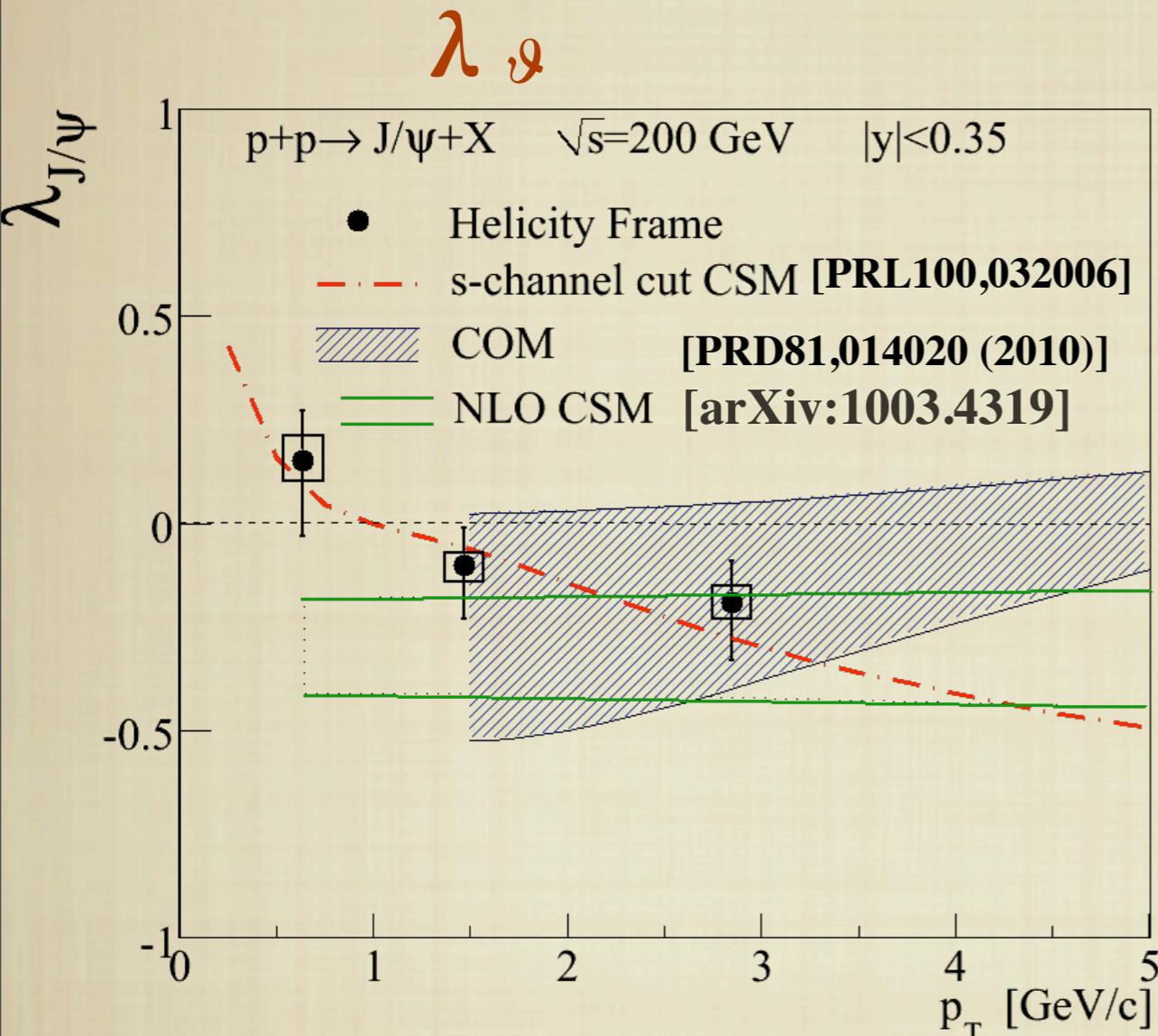
**measurement requires excellent knowledge of the detector acceptance**

# First Results

mid-rapidity |  $\eta$  | < 0.35 [Phys. Rev. D82, 012001 (2010)]

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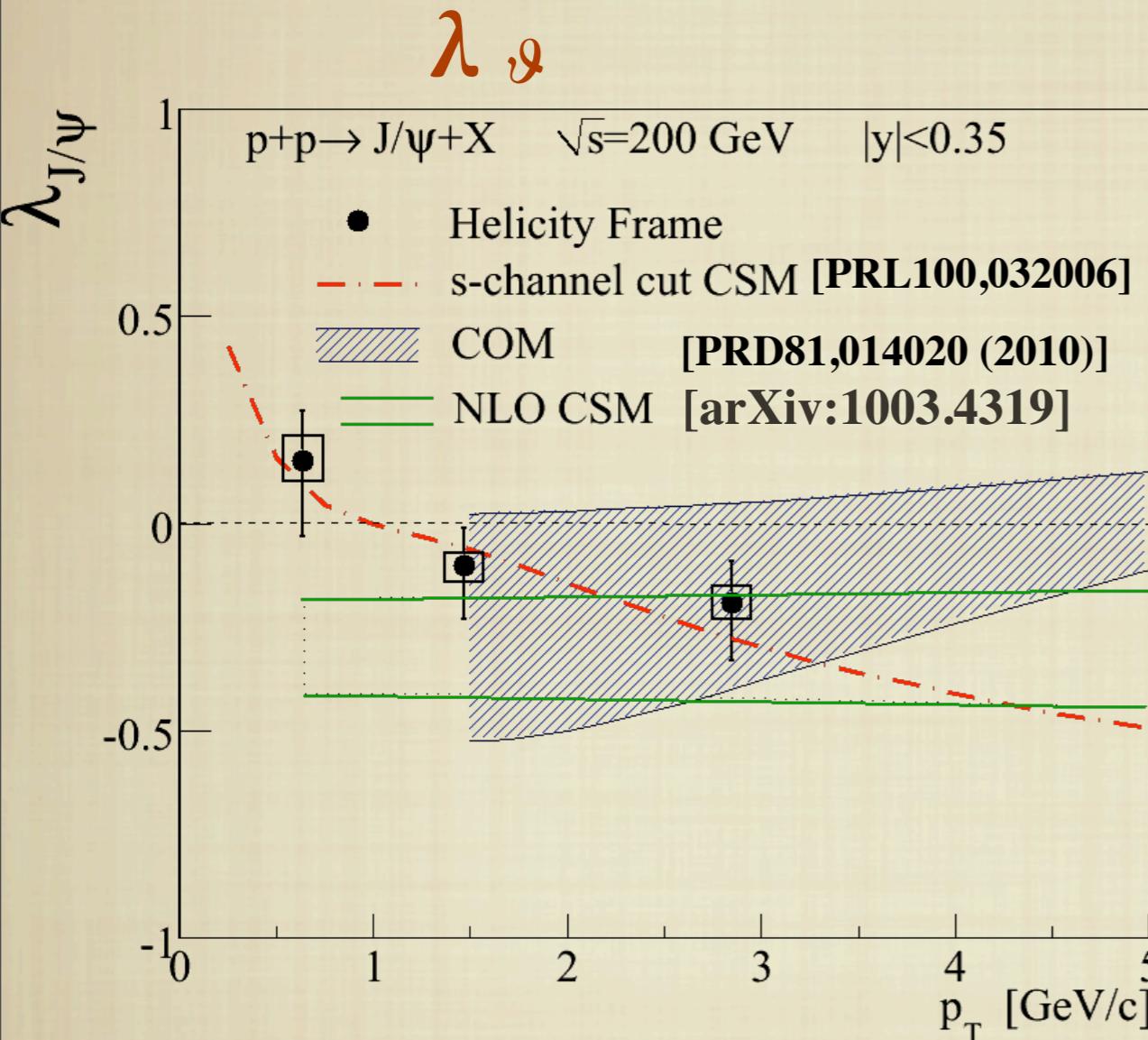
mid-rapidity  $|\eta| < 0.35$  [Phys. Rev. D82, 012001 (2010)]



- $J/\psi$  polarization in Helicity frame consistent with zero with a slightly ( $1.8\sigma$ ) trend towards longitudinal polarization ( $\lambda_{J/\psi} < 0$ ) for  $p_T > 2 \text{ GeV}/c$
- consistent with both CS and CO charmonium state formation

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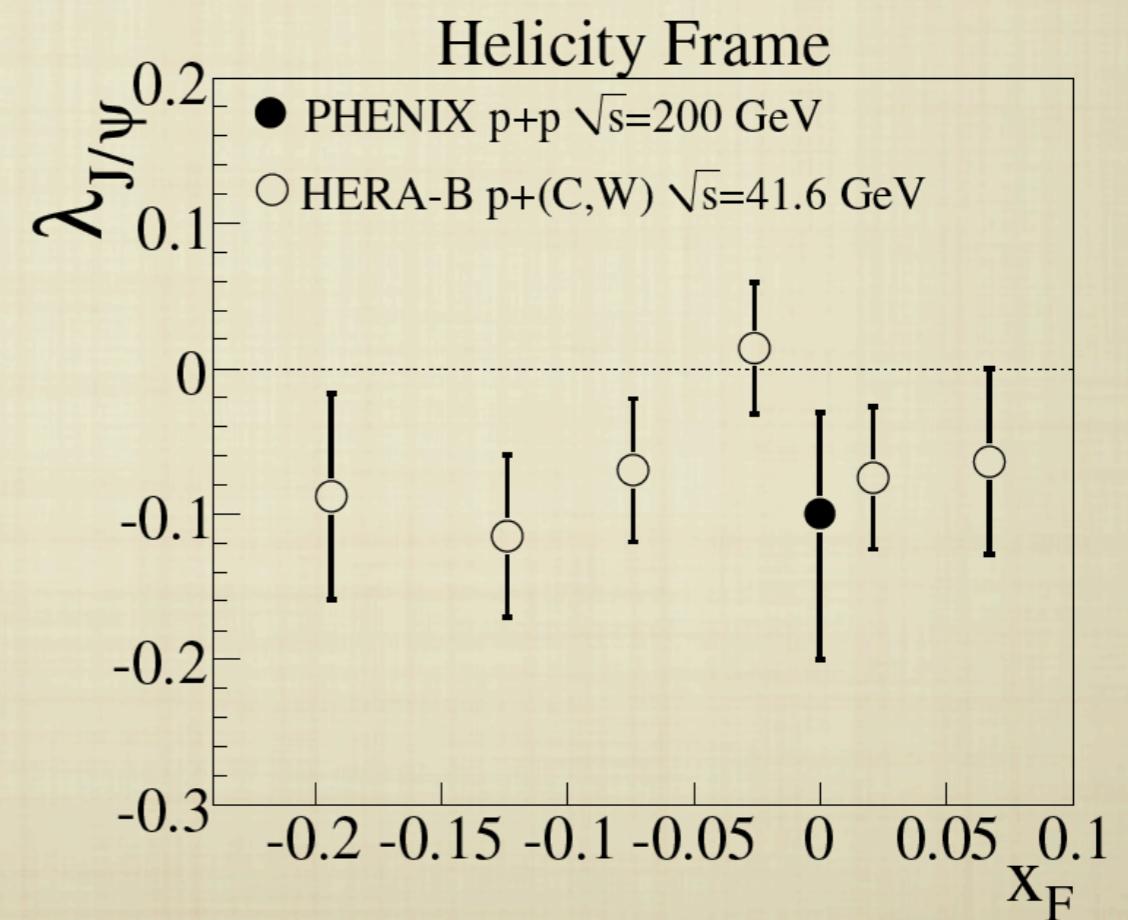
**mid-rapidity | $\eta$ |<0.35 [Phys. Rev. D82, 012001 (2010)]**



**also consistent with recent fixed target HERA-B results**

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**consistent with both CS and CO charmonium state formation**

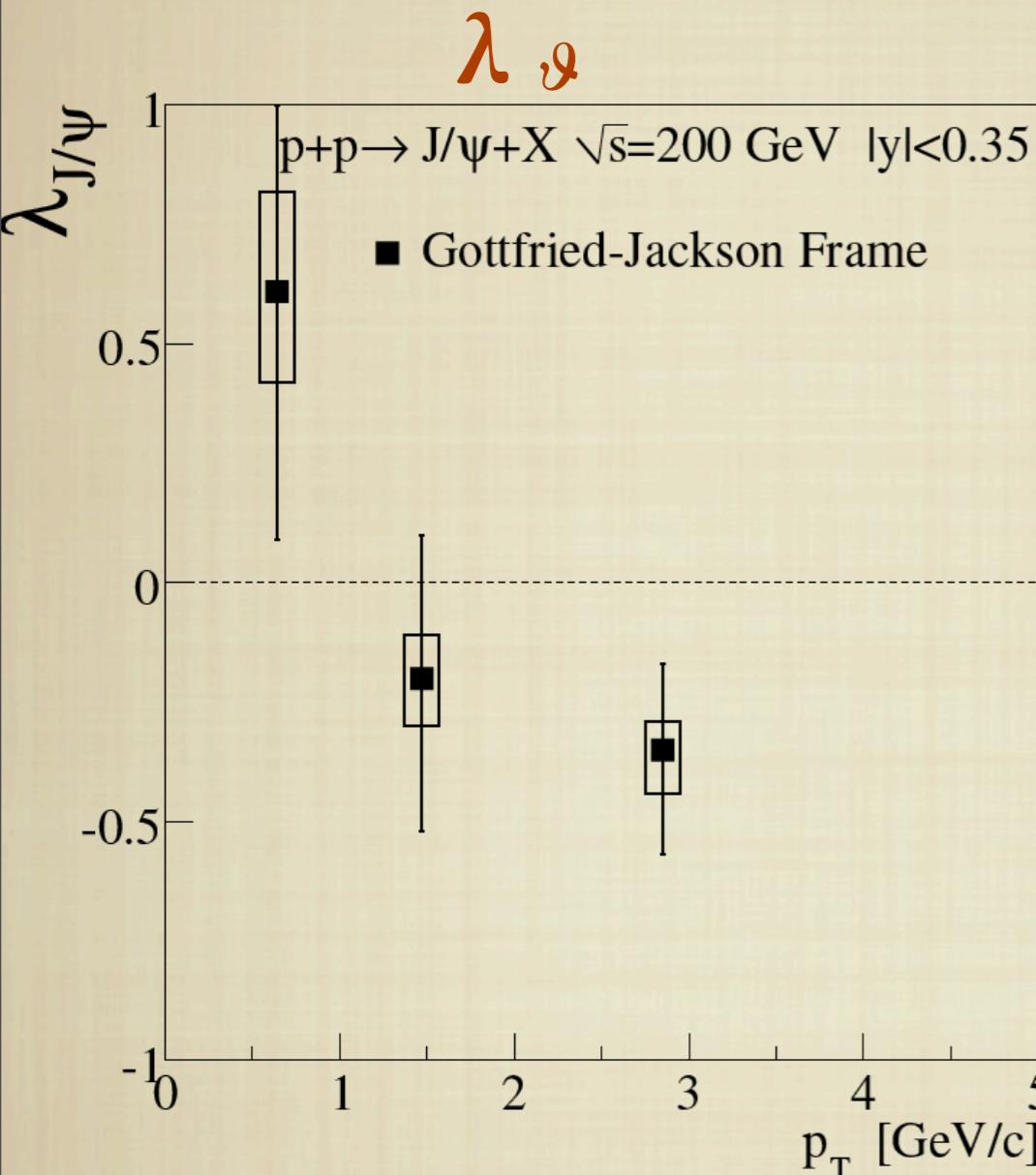


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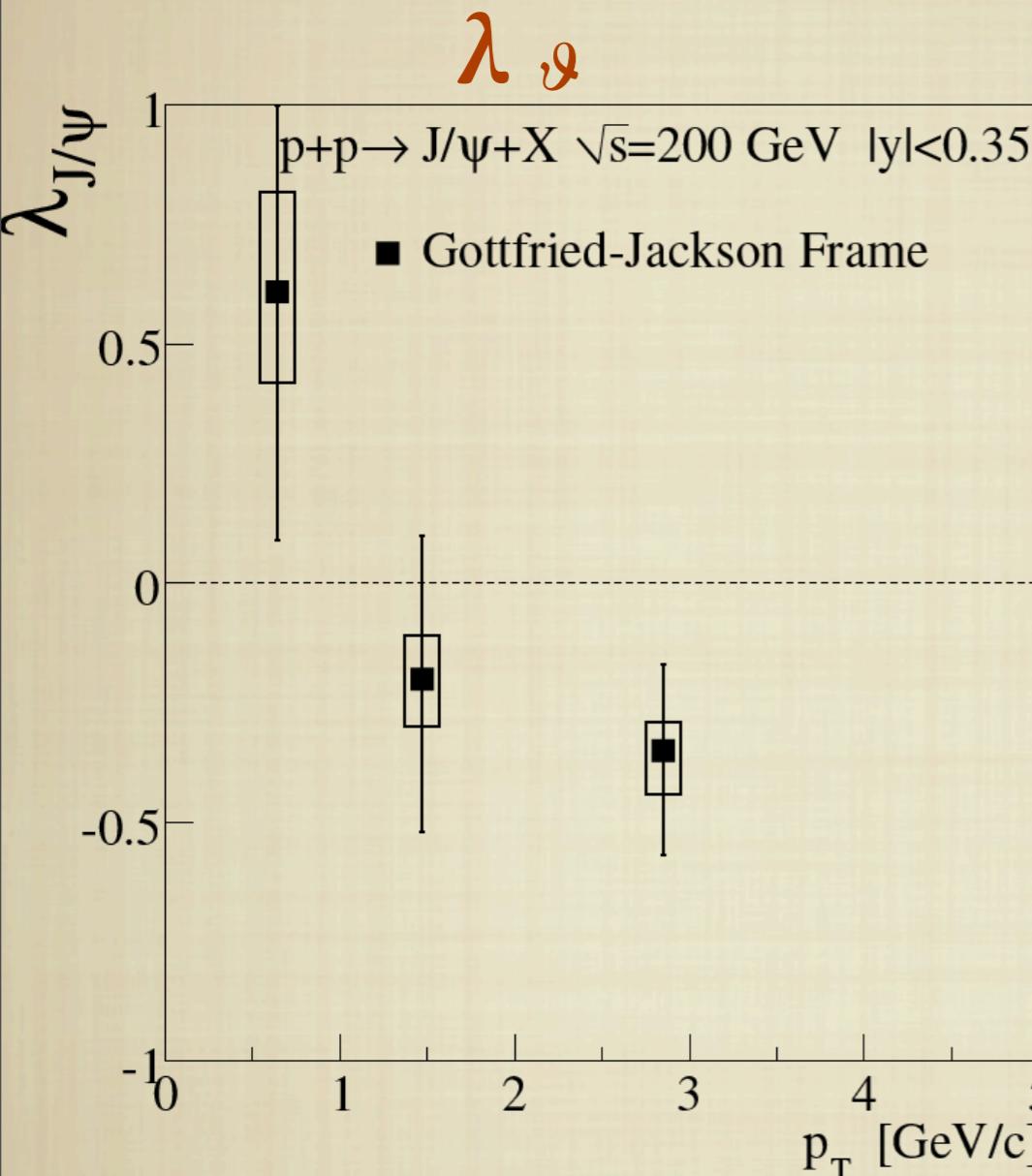
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□ result in Gottfried-Jackson (GJ) frame  
similar to Helicity (HX) frame

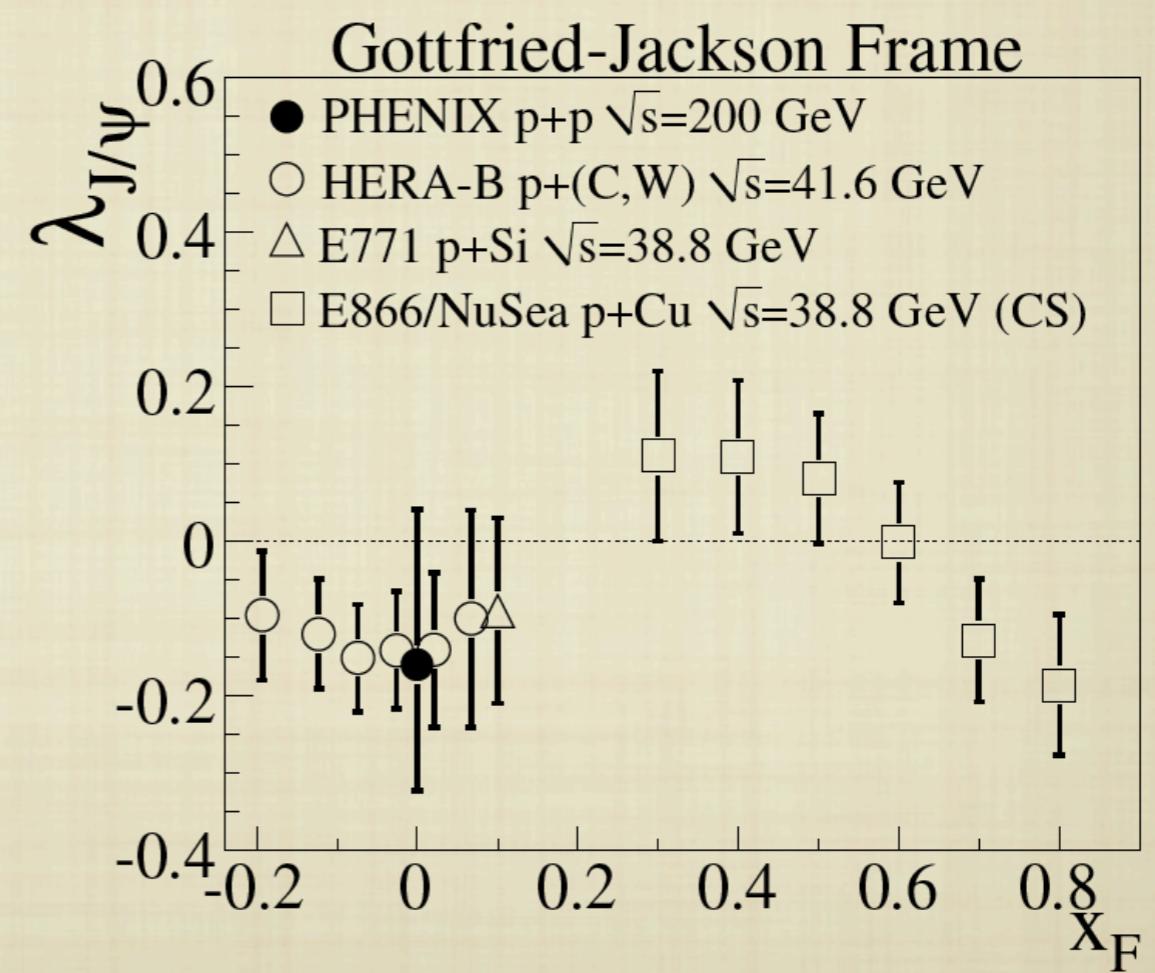
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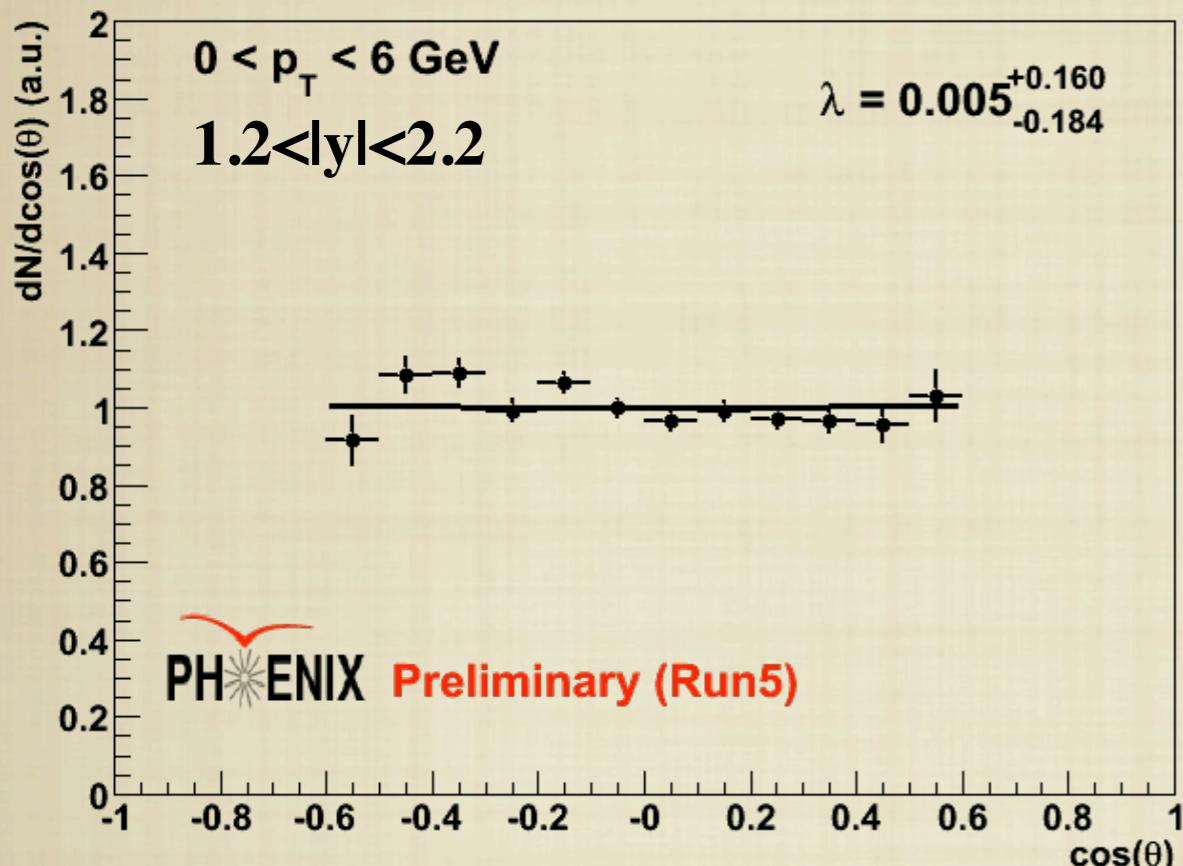
□ also consistent with fixed-target experiments

□ result in **Gottfried-Jackson (GJ) frame**  
**similar to Helicity (HX) frame**



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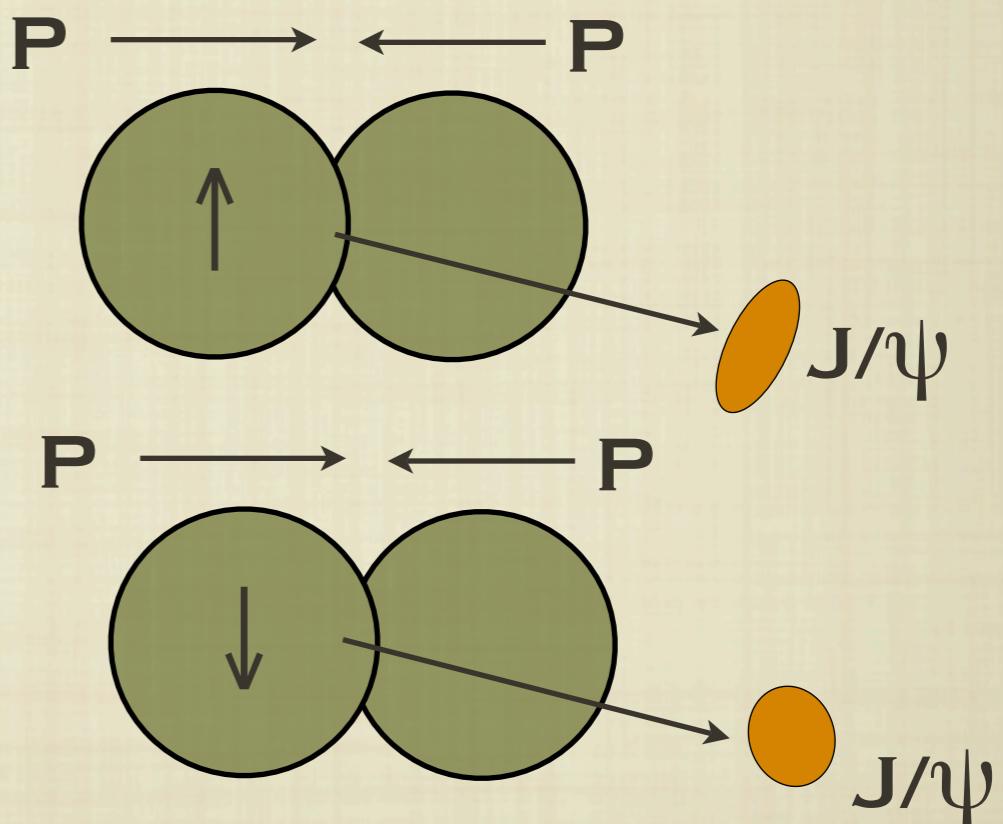
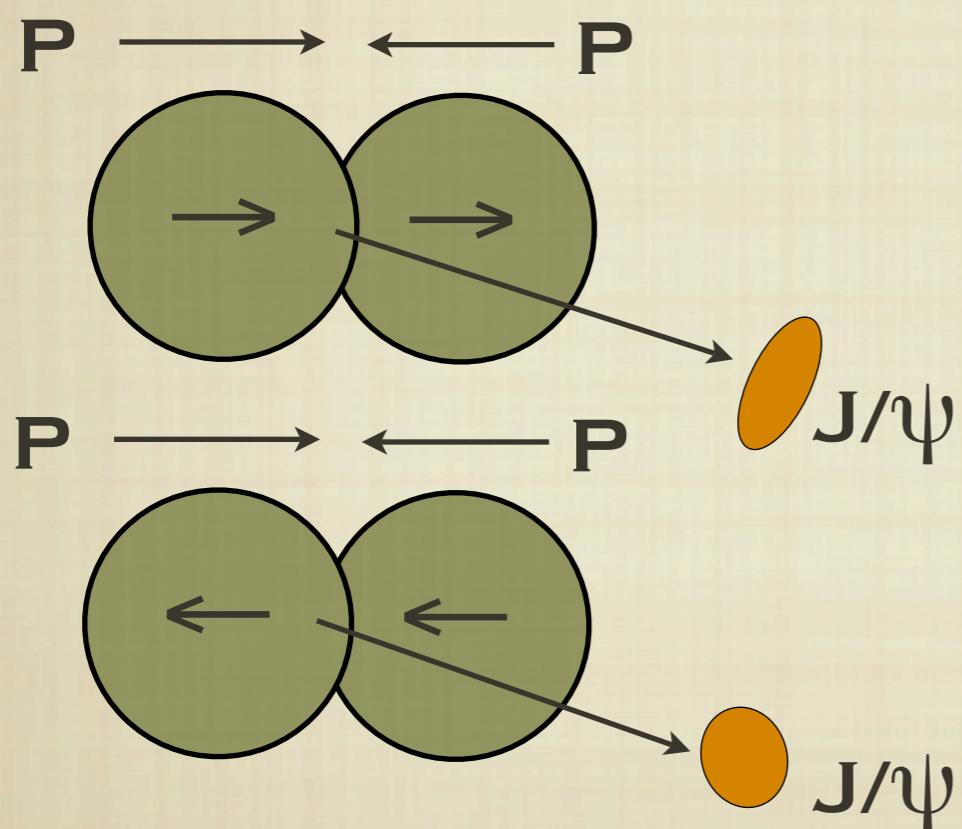
forward and backward rapidity  $1.2 < |y| < 2.2$



- only integrated  $p_T$  result for now
- preliminary result shows zero  $\lambda_\vartheta$  in Helicity frame
- additional discrimination btw. color singlet and color octet dominance in  $J/\psi$  production
- coming soon: results for  $\lambda_\vartheta$ ,  $\lambda_\varphi$ ,  $\lambda_{\vartheta\varphi}$  in HX, GJ-backward, GJ-forward, CS and frame invariant  $\lambda$

# SPIN TRANSFER TO J/ $\psi$

- can the J/ $\psi$  spin alignment change with the proton spin?
- what can we learn if this happen?
  - gluon helicity distribution in longitudinal double spin polarization asymmetry?
  - orbital momentum in transverse single spin polarization asymmetry?
  - effects of the c $\bar{c}$  hadronization cancel out in a polarization asymmetry measurement ?

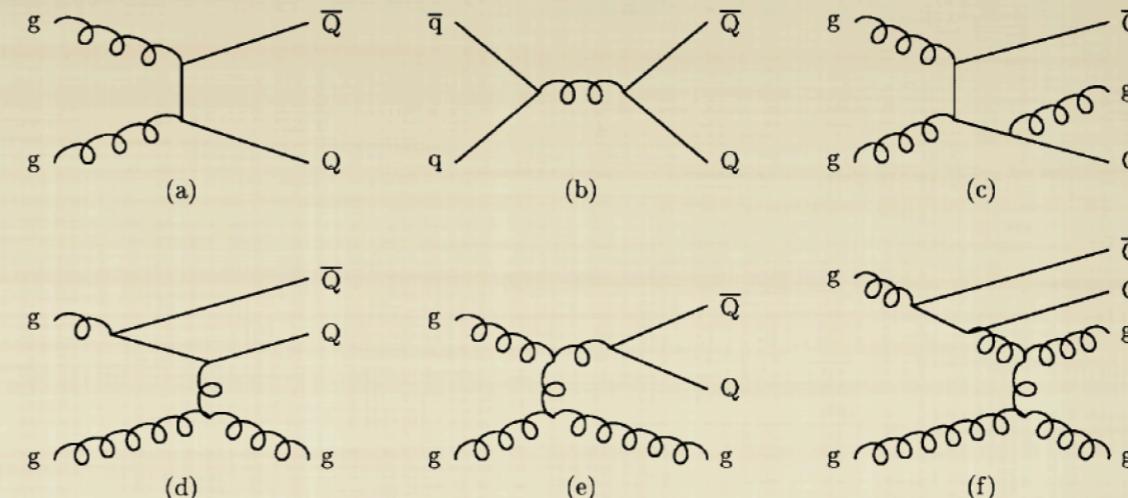


- starting studies: systematic uncertainties from the detector acceptance cancel out in this measurement

- **measurement of the decay angular distribution of  $J/\psi$  complementary to understand the charmonium production mechanism**
- **more mathematical tools available to interpret angular distribution measurements**
- **measurement requires a precise knowledge of the detector**
- **first PHENIX results at mid-rapidity shows a small trend for longitudinal alignment of  $J/\psi$**
  
- **angular distribution results in forward and backward rapidities coming soon**
- **promising measurements of spin transfer from RHIC polarized beams**

# BACKUP SLIDES

- **$Q\bar{Q}$  are mostly formed from gluons**



- **scenarios for the hadronization in quarkonia**

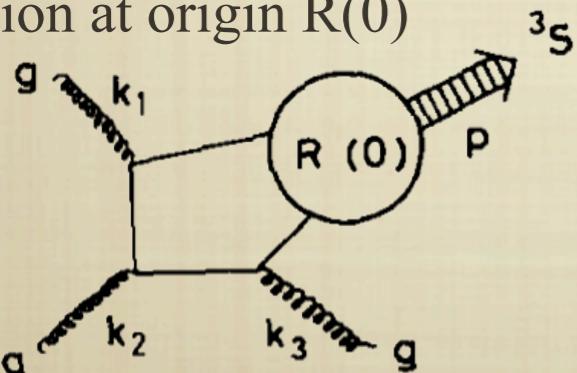
### Color Evaporation Model

- ❖ all quarkonium states are  $Q\bar{Q}$  below  $H\bar{H}$  ( $H=D,B$ ) threshold

$$\sigma_{c\bar{c}}(\hat{s}, Q^2) = \mathcal{F}_c \int_{(2m_c)^2}^{(2m_D)^2} d\hat{s} \frac{d\sigma_{gg}(\hat{s}, Q^2)}{d\hat{s}}$$

### Color Singlet Model

- ❖  $Q$  and  $\bar{Q}$  need to be on-shell
- ❖ production matrix density couplet with wave function at origin  $R(0)$



- ❖ wave function determined from potential models

### Non-relativistic QCD

$$(Mv^2)^2 \ll (Mv)^2 \ll M^2 \quad (\nu_c^2 \approx 0.3c, \nu_b^2 \approx 0.1c)$$

$v \equiv Q$  and  $\bar{Q}$  velocity relative to  $Q\bar{Q}$

- ❖ pQCD calculation is expended in  $v$
- ❖ projection to  ${}^2S+{}^1L_J$  include color octet states

$$\begin{aligned} |\psi_Q\rangle &= \mathcal{O}(1) |{}^3S_1^{(1)}\rangle + \mathcal{O}(\nu) |{}^3P_J^{(8)} g\rangle \\ &+ \mathcal{O}(\nu^2) |{}^3S_1^{(8)} gg\rangle + \mathcal{O}(\nu^2) |{}^3S_0^{(8)} g\rangle + \dots \end{aligned}$$

- ❖ non-relativistic factors  $\mathcal{O}(\nu)$  tuned from experimental results, color octet states domain S-wave yields

